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Utilization of seismic attributes for structural pattern detection In Bualawn, Dor Mansour fields, Western Sirt Basin, Libya.

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Highlights

- **Conjugate growth faults in NW-SE and NE-SW direction, dipping toward SW with antithetic faults dipping in opposite direction to the growth faults and other minor faults were identified manually and then tested by discontinuity attributes.**
- **Fault system is represented by a fracture system comprising long en echelon seismic faults and several discontinuities. This system of en echelon faults was initiated by left-lateral wrenching movements. This wrenching system has been identified by negative and positive flower structure along the releasing and restraining bends.**
- **A periodic strike-slip movement along deep seated basement faults has developed many structural features, such as horst-graben styles, which is the orientation of the transtensional movements linked to the Upper Cretaceous Succession.**

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ABSTRACT

An integrated approach to the study of fault patterns carried out in the complex geological structures of Bualawn, Dor Mansour fields by using multiple seismic attributes of 3-D seismic data. Each type of geological structure event usually generates a unique seismic signature that can be recognized and identified. This paper highlights the practical importance of analyze integrated attributes and interpret them within the context of an appropriate structural deformation. Many of discontinuity attributes such as variance, 3DEE (3D edge enhancement), ant tracking, chaos and structure smoothing have been selected to delineate fault styles and their displacement effectively, which cannot be fully delineated using seismic amplitude data. Conjugate growth faults in NW-SE and NE-SW direction, dipping toward SW with antithetic faults dipping in opposite direction to the growth faults and other minor faults. The faults were identified manually and then tested by discontinuity attributes. Fault system is represented by a fracture system comprising long en echelon seismic faults and several discontinuities. This system of en echelon faults was initiated by left-lateral wrenching movements. This wrenching system has been identified by negative and positive flower structure along the releasing and restraining bends. The current understanding that these faults are strike-slip faults despite the absence of extensive horizontal displacements along them as shown on different time slices. A periodic strike-slip movement along deep-seated basement faults have developed many structural features, such as horst-graben styles, which is the orientation of the transtensional movements linked to the Upper Cretaceous Succession.

1. Introduction

The interpretation of faults in any seismic interpretation process has significant importance during the exploration. Faults are important in trapping hydrocarbon into accumulation for drilling. The identifying and mapping of fault structures often help in the determination of the size, geometry and the level of compartmentalization of hydrocarbon reservoirs (Jibrin, 2009). Fault interpretation is an important component in determining the structural information in the Bualwan, Dor Mansour fields to understand the impact of regional stress during its evolutionary history. The conventional way of interpreting fault is achieved by manual picking of fault on a 3D seismic volume. It is most times not suitable for using these approaches to interpret fault since sometimes these faults are not seen clearly, due to the presence of noise.

Seismic attributes provide a quick way to visualize the trends of faults, which are hard to see or most times not visible on a different conventional seismic sections. Seismic attributes defined as all the information obtained from seismic data, either by direct measurements or by logical or experience based reasoning (Liner *et al.*, 2004). In this paper, we discuss the use of volumetric attributes such as structural smoothing, chaos, variance attributes, and 3D edge enhancement (3DEE) on 3D seismic data. The information from different seismic attributes is used to form fault geometry to interpret the structural pattern to examine the relationship between observed fault kinematics (fault polygon) and tectonic evolution, to try understanding important role of strike-slip fault system in the structural configuration and can generally be used to optimize well locations as prospect identification.

1.1 Location of Study Area

The area under investigation is the Bualawn Dor Mansour Fields located in the central part of west of Sirt Basin, Its cover an area about 450 Km^2, which is located between (latitude; 28° 30' and 28° 35' north, and longitude; 18° 35' and 18° 45' east) (Fig. 1A).

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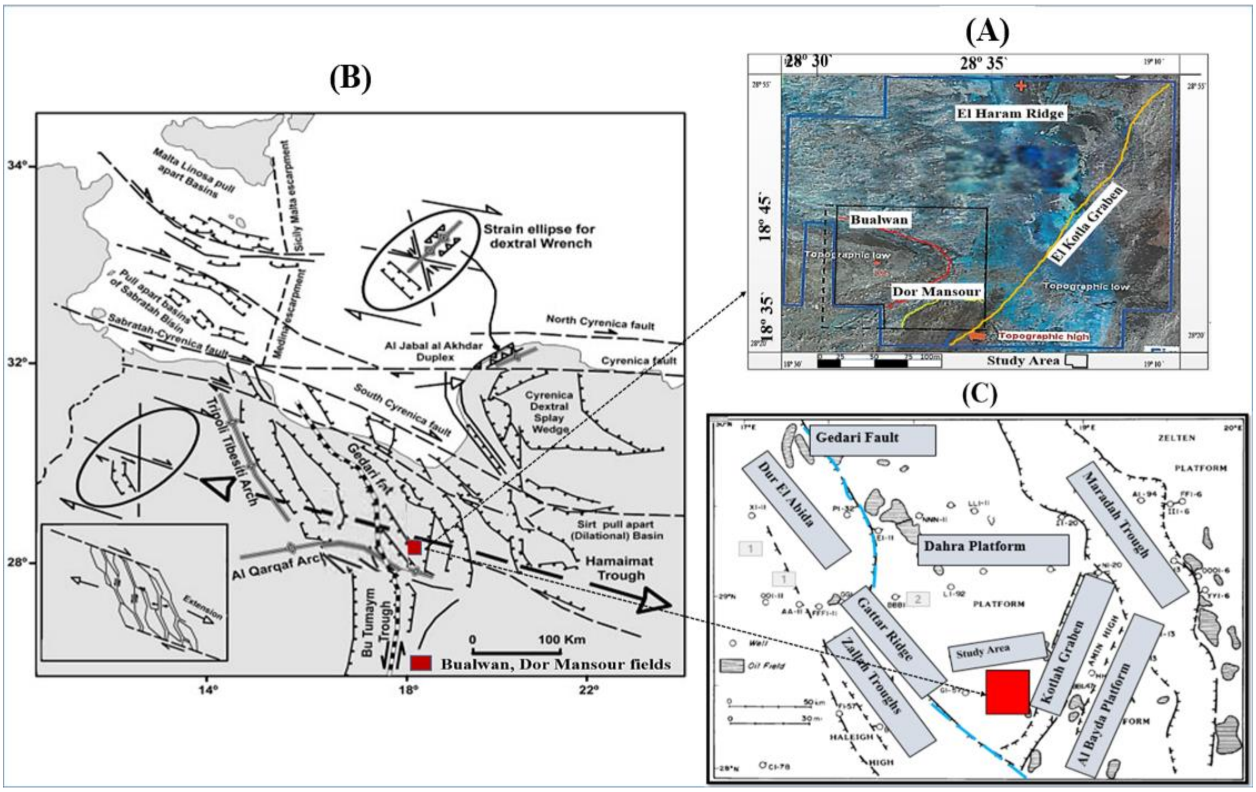

Fig. 1. (A) Tectonic interpretation of Sirt rift complex (Anketell, 1996), (B) Satellite image shows boundary and topography of the study area Bualwan, Dor Mansour Fields and (C) structural elements within study area (Gumati and Kanes 1985).

2. Geologic and tectonic setting

The structural pattern of the Sirt Basin being a rift type has evolved by strike-slip tectonics, which is originates from the major regional right lateral movement along the Sahara Cyrenaica Fault Zone (SCF) related to the opening of the Atlantic Ocean (Anketell, 1996), which is divided the basin into Horsts and Grabens during the Early Cretaceous period (Fig. 1). Consequently, this has in turn to varying degrees impacted on the attitude of the overlying formations (Abadi, 2002).

This rift basin of the Early Cretaceous has evolved Pre-rift sediments (Paleozoic-Triassic) NNE-SSW trend, followed by Upper Cretaceous Syn-rift basin, subdivided into three stages which are; began with continental-marine siliclastic rocks, to marine siliclastics and carbonate rocks and finally continental siliclastic strata NW-SE trend. The third cycle is Post-rift basin fill, deposition characterized by Carbonate and evaporate strata NNW-SSE (Roohi, 1996). In the Bualwan, Dor Mansour fields syn-depositional structures are prevalent and characterize the nature of rift subsidence.

2.1 Major impact of structural elements in the study area

The study area is located in the southwestern part of Dahra Platform, where it occupies a 40,000-km^2 area. Bounded by Dur El Abida and Zallah Troughsto the west, which is separated by Gedari Fault Zone (GFZ). Gedari Fault is trending NNE-SSW, which provide a sense of relative down throw across the fault zone (Jerzykiewicz, *et al.*, 2002). On the southwest margin, the Gattar Ridge is formed by down faulting to the WSW, and by the Maradah Trough to the east, and is bounded on the south by the NNE-SSW trending Kotlath Graben, which separates it from Al Bayda Platform (Fig. 1C).

2.2 Evolution of regional stress regime

A multi-phase subsidence from the Cretaceous to recent periods in respect to the changes of regional stress, a combined strike-slip movement along SCFZ and normal extension mechanism along has been occurred. The initiation of rift oblique basement lineaments during extension can yield geometries similar to those formed during strike-slip (transtensional) movement. Understanding the variation between the two structural styles and their stress regime is important (Morley *et al.*, 2004).

3. 3 D Seismic Data and Attributes conditions

The 3D seismic data volume imported to Petrel Software 2015, contains 500 inline and 600 crosslines, where inputted seismic was zero-phased. Seismic attributes are often sensitive to noise present in seismic data. It is advisable to run a spatial filtering filter to remove the noise while retaining the geometrical details. This can be achieved by applying structural smoothing to reduce background noise and to improve the spatial continuity of the seismic signal. Fig. 2 shows the raw data before and after the application of structural smoothing, it can be seen that the data quality has been enhanced, a better result since the faults are more pronounced in the data.

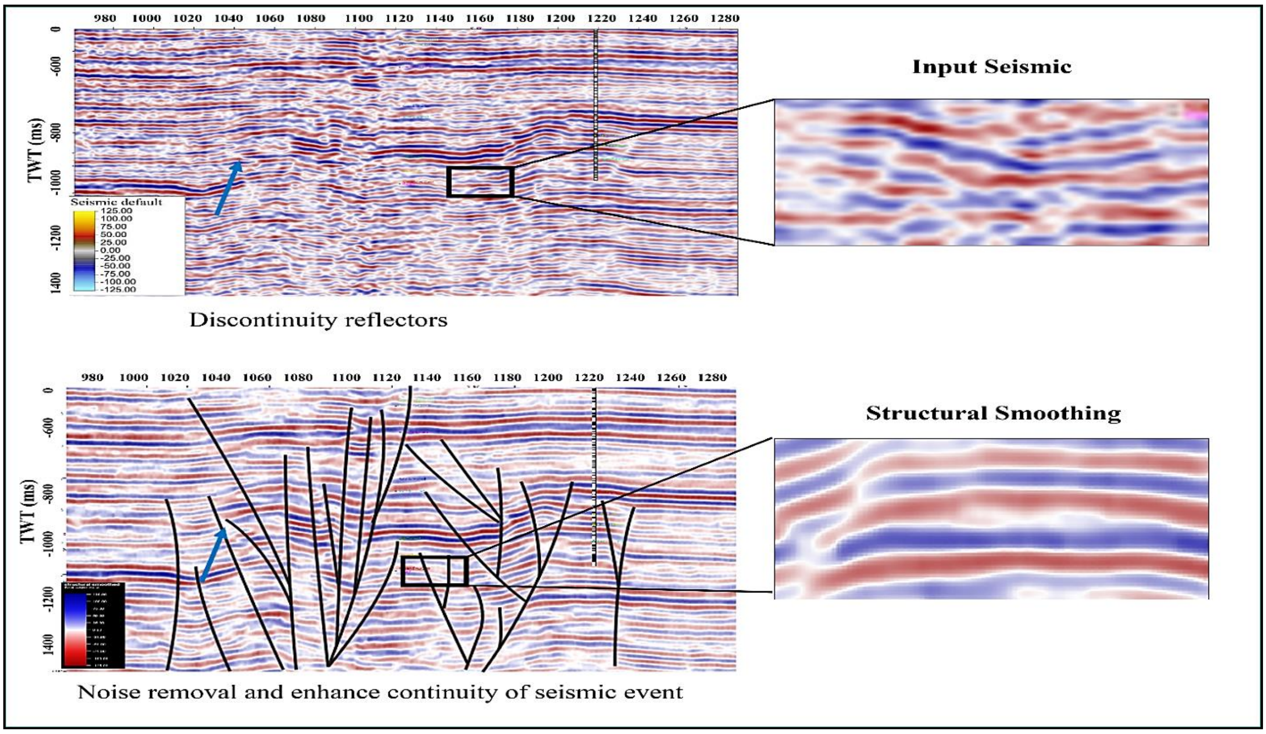

Fig. 2. Structural smoothing attribute reduce noise effects and enhance the quality.

3.1 Complex seismic trace

The Hilbert transform is used to calculate attributes in seismic interpretation includes amplitude, phase and frequency instantaneously (Hardage, 2010). The recognition of the recorded signal representing as the kinetic portion of the energy flux. Hilbert transform programs used to compute the potential component from its kinetic part, then realizing the potential component for extracting useful instantaneous information, which made possible practical and economical computation of all of the complex trace attributes.

The complex trace z (t) is comprised of the real seismic trace x (t) and an imaginary seismic trace y (t). The imaginary trace y (t) is calculated using the Hilbert Transform to apply a 90 degrees phase shift to every sinusoidal component of a signal (Fig. 3). At any time on this trace, a vector a (t) can be calculated that extends perpendicularly away from the time axis to intercept z(t) from this point, instantaneous amplitude, instantaneous phase, and instantaneous frequency can be calculated.

4. Automatic fault extraction technique/ant tracking

In this study, ant tracking used as seeds to interpret areas with discontinuity, to deliver automatic fault extraction process for the models. Generating ant track volume starts by preconditioning the seismic volume, as following steps:

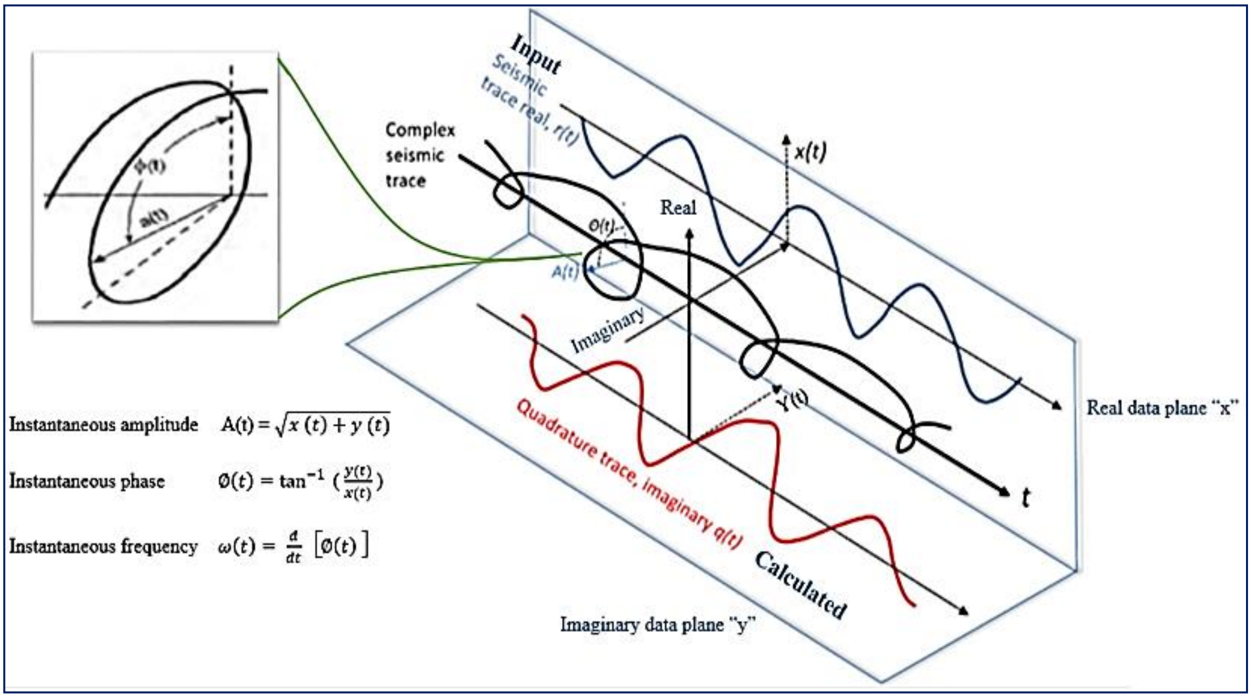

Fig. 3. Calculate instantaneous seismic attributes from the complex seismic trace (modify after Hardage, 2010).

4.1 Attribute Segmentation

Segmentation techniques are used to isolate or decompose seismic sections into meaningful of the desired object or region. The process subdivided an image into its constituent parts. Quantitative measurement of object features allows classification and display of the attribute image.

Cropped used to isolate specific depths interval include Upper Cretaceous succession ranging from 600 ms to 1200 ms entire seismic volumes (Fig. 4). To all extra advantage of speed in carrying out interpretation by minimizing the size of the store to be much easier and quicker, and to validate properties of the sub volume before making general applications. Attribute analysis such as ant track process of fault extraction cropped at specific target zones to pre-test before final parameter application to the whole seismic volume. The time taken for this attribute to run completely depends on the number of faults in the data, and the parameters used.

4.2 Attribute collection

The effective implementation of the attributes can be achieved by collecting two or more kind of attribute with each other. In such a faulted area, we used, structural smoothening and Chaos attribute, because these attributes are sensitive to faults, so these attributes were used as input data to run the ant attribute separately to see faults clearly that where difficult to display on the dataset.

4.2.1 Structural Smoothing

Smoothing attribute played an important role to understand structure revolution and their effects in the sediment deposits by delineating features in terms of horizons and faults, extending of faults in the deeper depth with different intensities and styles, reflect activity tectonic deformation.

4.2.2 Chaos Attribute

The study used chaos attribute to distinguish lithology variation based on different sediment facies, Upper Cretaceous marine deposits includes dolomite, limestone and shale, can be either in continuity or discontinuity bed. As shown in Fig. 5 uncolored values indicate minimum chaoticness correspond to continuity, and zones of maximum chaoticness indicate discontinuity of reflector character, which forms a basis to detect faults for automatic extraction.

4.3 Filters and Fault patches

Stereo net used to provide orientation filters for the ant agents, which places restriction to the azimuths and dips (Fig. 6) that the agents would allow for searching the seismic in lines and cross-lines. Select aggressive mode, which is applied to detect discontinuities. Create fault patches, which gives information to the fault details as to their trends/nature and provides a much faster structural overview for interpretation (Fig. 7).

5. Manual fault interpretation

The fault picked manually starts by assigned fault segments picking on inline sections of seismic with the trace appearing on the corresponding cross lines, within the Upper Cretaceous succession into a basement from 600 ms to 1400 ms. Many of the faults were identified and interpreted as fault sticks then converted to fault polygon. These represent line data of the interpreted faults and their geometry, some extending through the extent of the field known as major regional growth faults; few flank faults appearing on few of the lines (Fig. 8).

5.1 3D Edge Enhancement (3DEE)

Applied 3DEE attribute helped to increase the number of faults and fractures have been identified and further enhance their resolution. This makes the workload easier to get effective fault interpretation. 3DEE in In line 1040 (Fig. 9) detected the tilted fault blocks related to extension normal fault with strike-slip, produce negative flower structure below TWT 600 ms because of the Cretaceous rift, which ends in Paleocene.

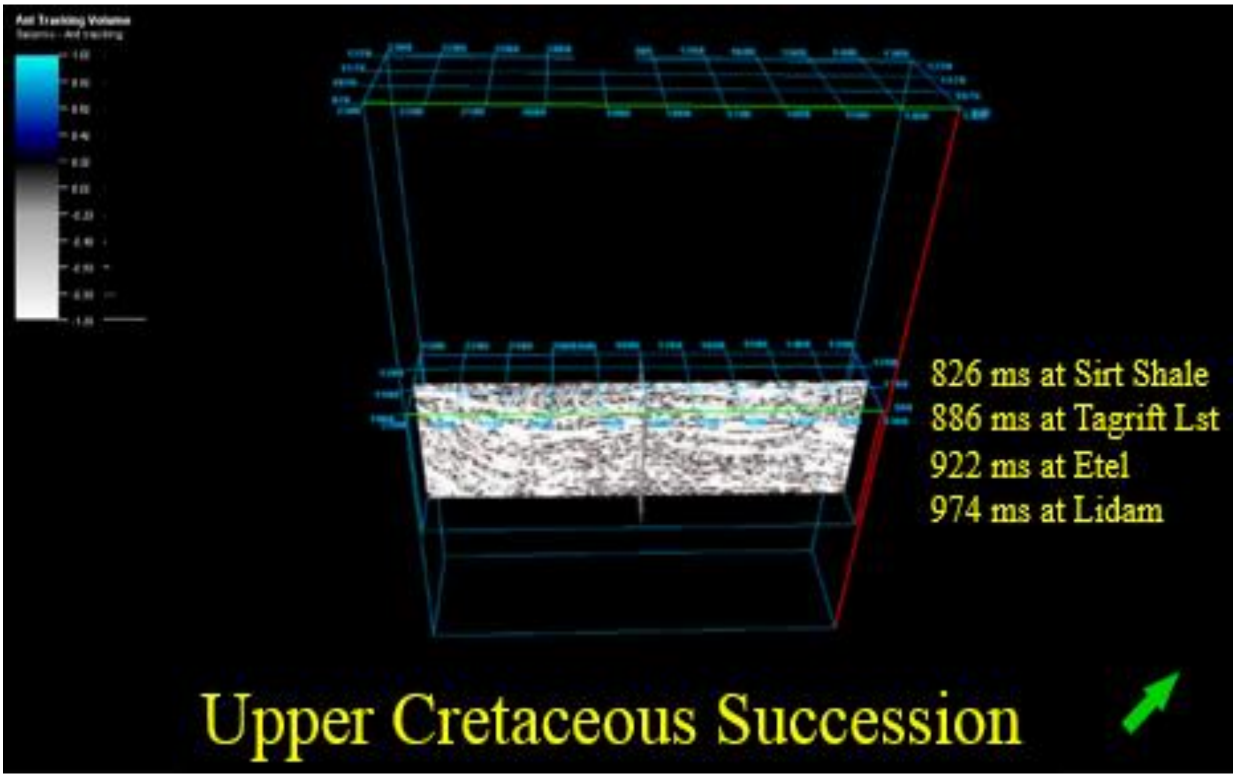

Fig. 4. Creation of a cropped volume of the active seismic cube and interactively use handles to manipulate size and shape zone of interest for ant track process and visualization.

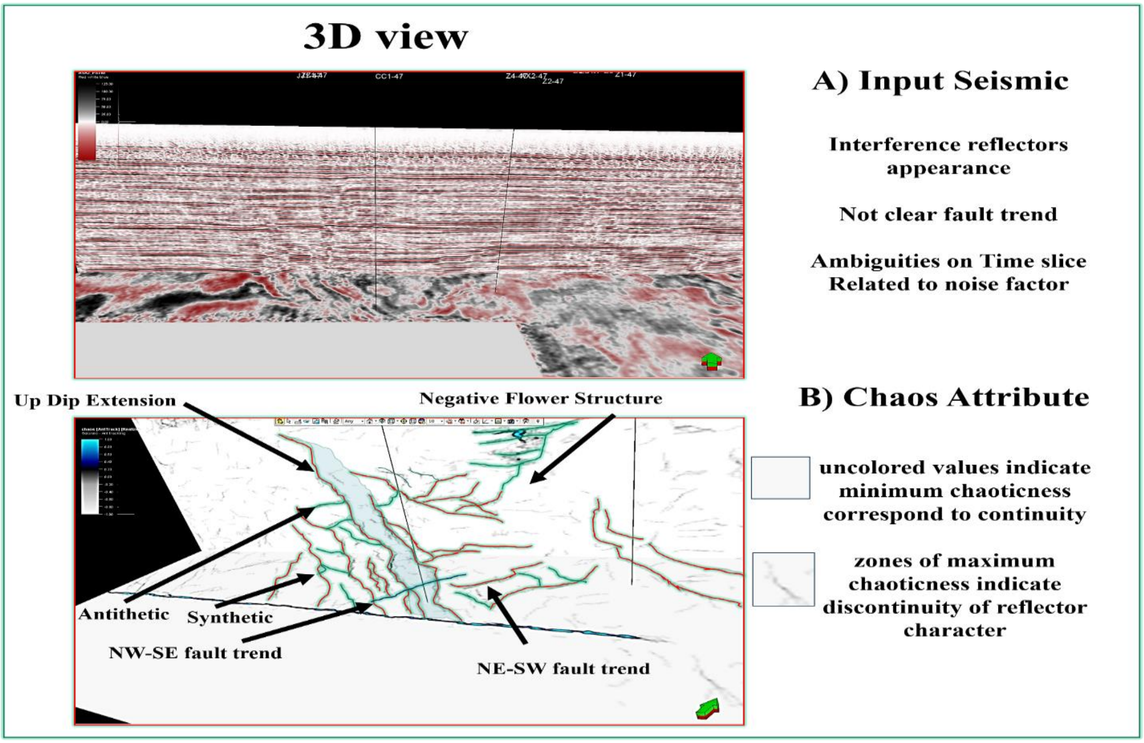

Fig. 5. 3D view display inline crossed by time slice, (A) original seismic (B) chaos attribute.

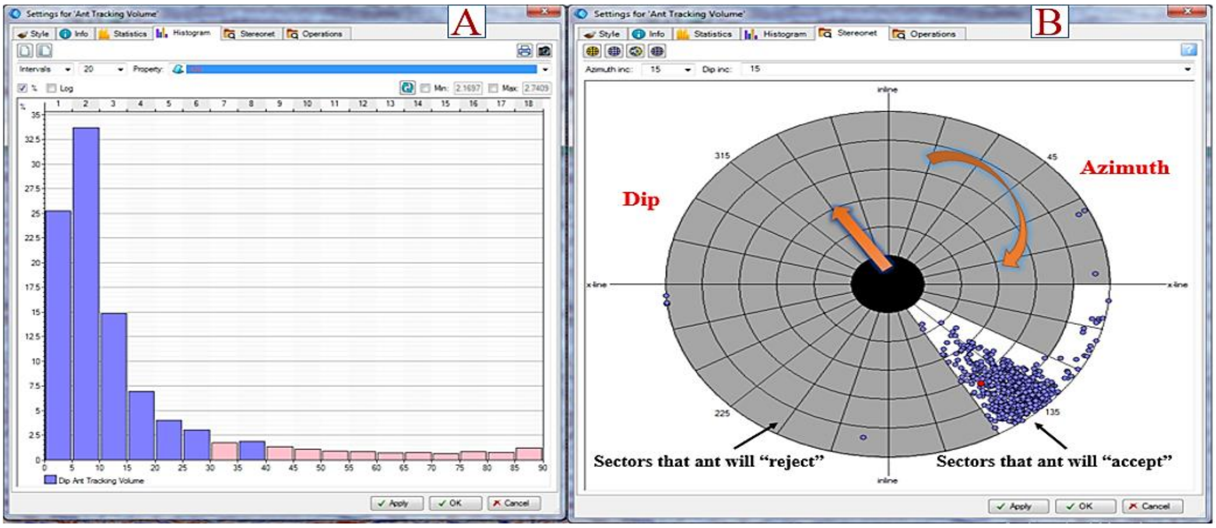

Fig. 6. Frame (a) shows the ant parameter with ant mode, ant track deviation, ant step size. Frame (b) shows the stereo net sectors of the dip and azimuth with the seismic inline/cross lines.

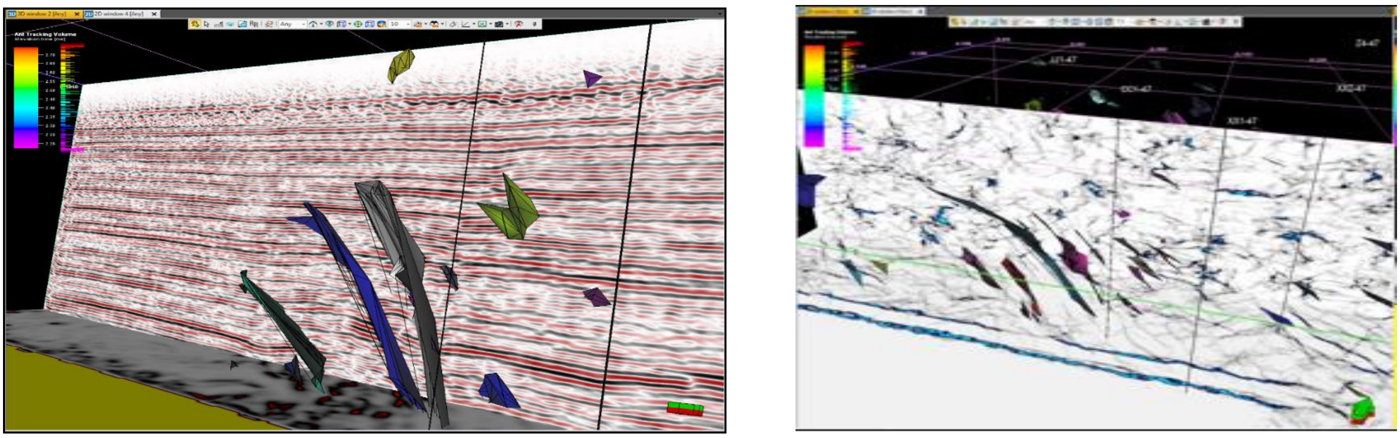

Fig. 7. (A) Fault patches generated with a cropped seismic section of the whole seismic volume. (B) Extracted fault patches with the chaos attribute within the cropped seismic section.

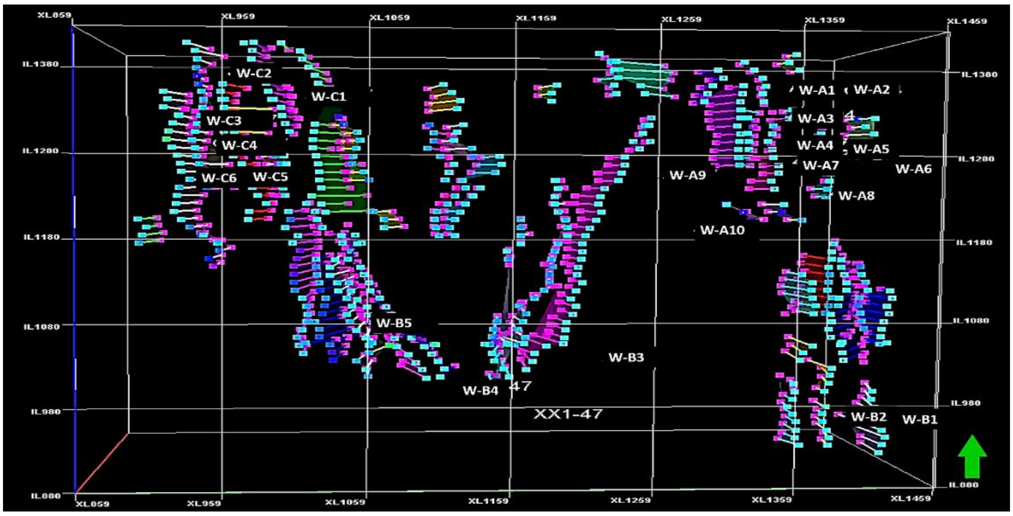

Fig. 8. Fault sticks show main fault segments.

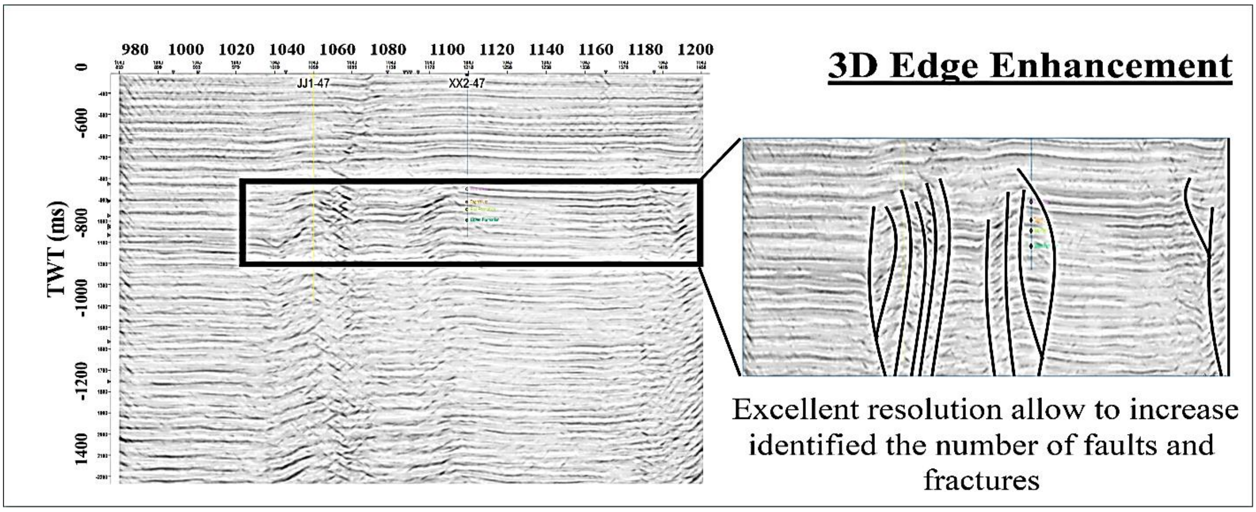

Fig. 9. Shows 3D Edge Enhancement attribute.

5.2 Structural architecture

The internal structure of the investigation area have been studied along two seismic profiles AA' and BB" as shown in the Lidam Time structure map (Fig. 10A). The study delineates the along-dip and across-strike variations in the distributions and thicknesses of the stratigraphic units, using the well-recognized seismic interfaces, and map the fault geometries and patterns affecting the stratigraphy at depth.

5.2.1 Profile A-A'

Inline1040 seismic profile in the southern part of the study area (Fig. 10) represents major faults have divergent style showing a negative flower structure of strike-slip fault. However, produce a pull apart opening in E-W blocks with opposite up thrown horst structure trending to NW-SE, steeply dipping in southwestern part as distinctive depression, and to NE-SW dipping in the northwest as a subsidence in the north-central part between to master fault, which was related to the extension, accumulate sediment load, and reactivation in Paleocene period. These two faults intersect in the basement at nearly 1200 ms, with high angle faults that bound horsts and grabens, which is represent extension related fragmentation. The second is low-angle detachments faults with associated basement (Fig. 10B). Both types of faults are related to the development of two superimposed stress fields, one related to tectonic and the other to gravitational collapse. The NW-SE faults that are parallel to the major structural trend of the basin controlled the rate of rifting and subsidence. Whereas the NE-SW structure modifies the pattern formed by the previous system to form the block structures.

Geoseismic model speculative possible propagation of secondary faults above major faulting resulting in horst and grabens and half-grabens, these secondary faults have parallel and sub vertical geometry influenced on sedimentary arrangement. Changes of stress on both side of fault gravitational sliding in transtesional stress to the SW, and contracted vertical and lateral duplexing in the transpressional stress to the NW and NE as triangle uplifted shape, this reflects changing in the tectonic event, because of strike-slip fault system corresponds to ancient deep fault related to basement.

5.2.2 Profile B-B'

Inline 1260 seismic profile goes through several structural domains. In the west of the profile, a mild structural high in the pre-Cambrian basement has been observed, above which the seismic reflectors are displaced by positive flower structure. In the mid-section of the profile, all formation and member boundaries display downward sagging, and the formation thicknesses increase, particularly that of Upper Cretaceous Formations. These observations occurred in this part of the basin during the Upper Cretaceous. In the western end of the profile, it is suggested that a major episode of subsidence might be basement beneath the sedimentary strata (Fig. 10C). A series of high angle, west reverse faults and fault-propagation folds, interpret these reverse faults and the associated asymmetrical folds as transpressional structures, which helped create the Uplift within the field. Diminishing effects of reverse faulting and folding stratigraphically upwards in the Upper Cretaceous (the Sirt Shale Formation) sedimentary units indicate that the main episode of transpressional deformation was completed by the Santonian age.

5.3 Variance Attribute

In order to test the accuracy of manually interpreted faults represented by fault sticks. Variance has the advantage to reveal the discontinuities, so in this study variance used as a structural guide by make the comparison. An overlay of variance detection with the manual seismic interpretation sticks and polygon showed excellent agreement between variance attribute showing fault highlighted by the darkest regions and manual fault interpretation displayed by fault polygon. Using variance seismic attribute maps on 3D seismic data at different time depths in order to delineate the fault and fold patterns of specific time frames in plan views.

The interpreted map (right) and its trace (left)(Fig. 11) of the Sirt Shale Formation at a time depth of 826 millisecond show the linear geometry of the NW-NE master fault with a left bend (releasing bend) along its strike and the distribution of en echelon normal faults in its hanging wall. The orientation of these en echelon faults (closely-spaced, parallel or subparallel, overlapping or step-like minor faults) is compatible with the main strike of extensional normal faults. Tagrift, Etel and Lidam formations at a time depth of 886, 922, 974 millisecond respectively, at this higher structural level in the study area show geometry of the NW Fault, which subdivided into two uplifted closure separated by constraining trough in the NW, having a left-bend along its strike. The occurrence of the en echelon normal faults associated with both the NW Fault systems indicates that transtensional deformation continued to affect the Cretaceous deposits in the North Sag (Fig. 10A). The NE-SW fault system has a major left-bend (restraining bend), where transpressional deformation produced en echelon fold trains oblique to the general orientation of the shear couple. The orientation of these en echelon faults with the main strike of extensional normal faults are consistent with the transpressional deformation patterns on seismic profiles B-B' (Fig. 10C). Strike-slip activity indicates that locally developed transpressional and transtensional deformation domains continued all the way through the Cretaceous times.

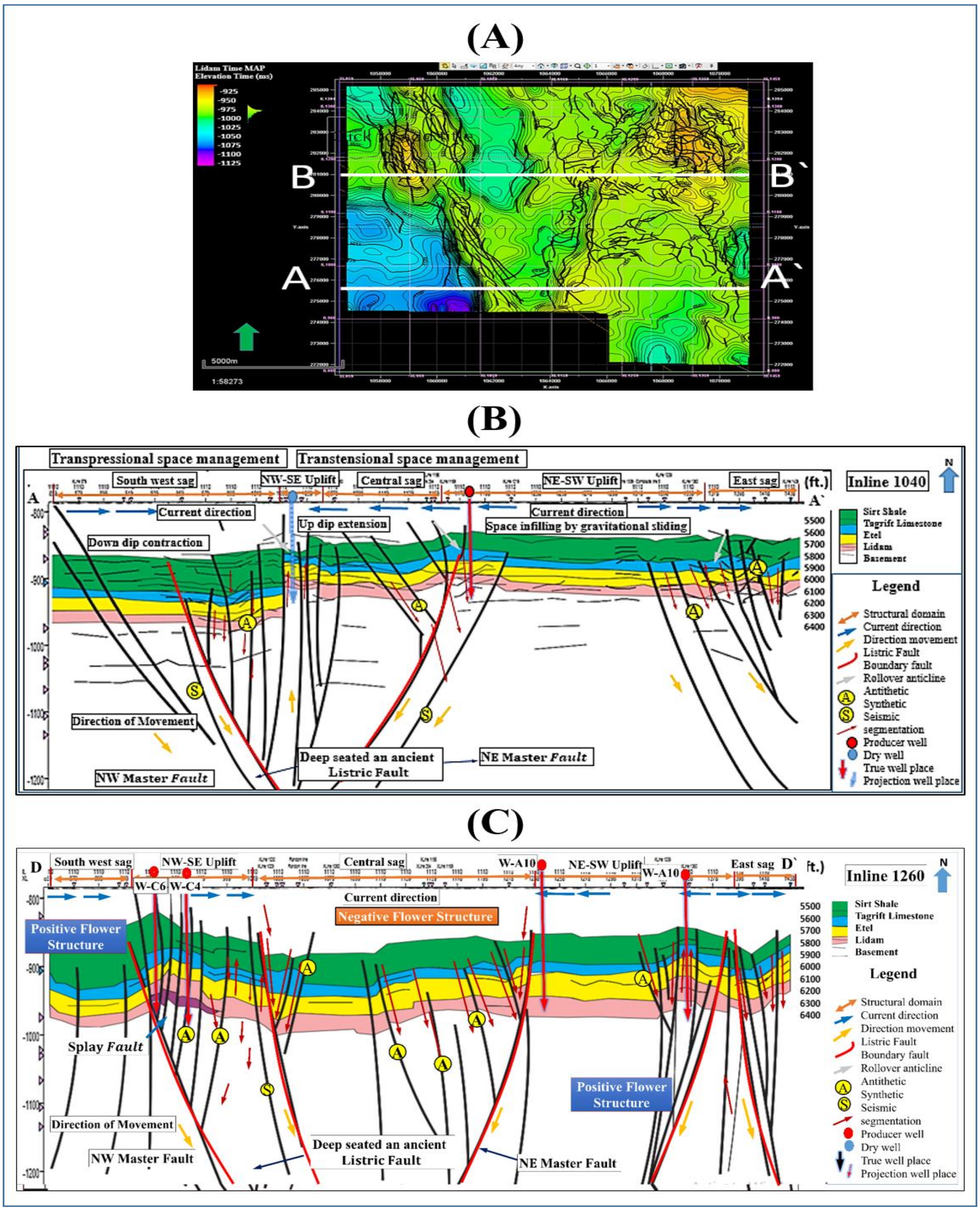

Fig. 10. (A) Lidam Time Structure Map with Cross Section Index AA` and BB`, (B) and (C) Typical Geological Profiles of Inline 1040 and 1260 respectively.

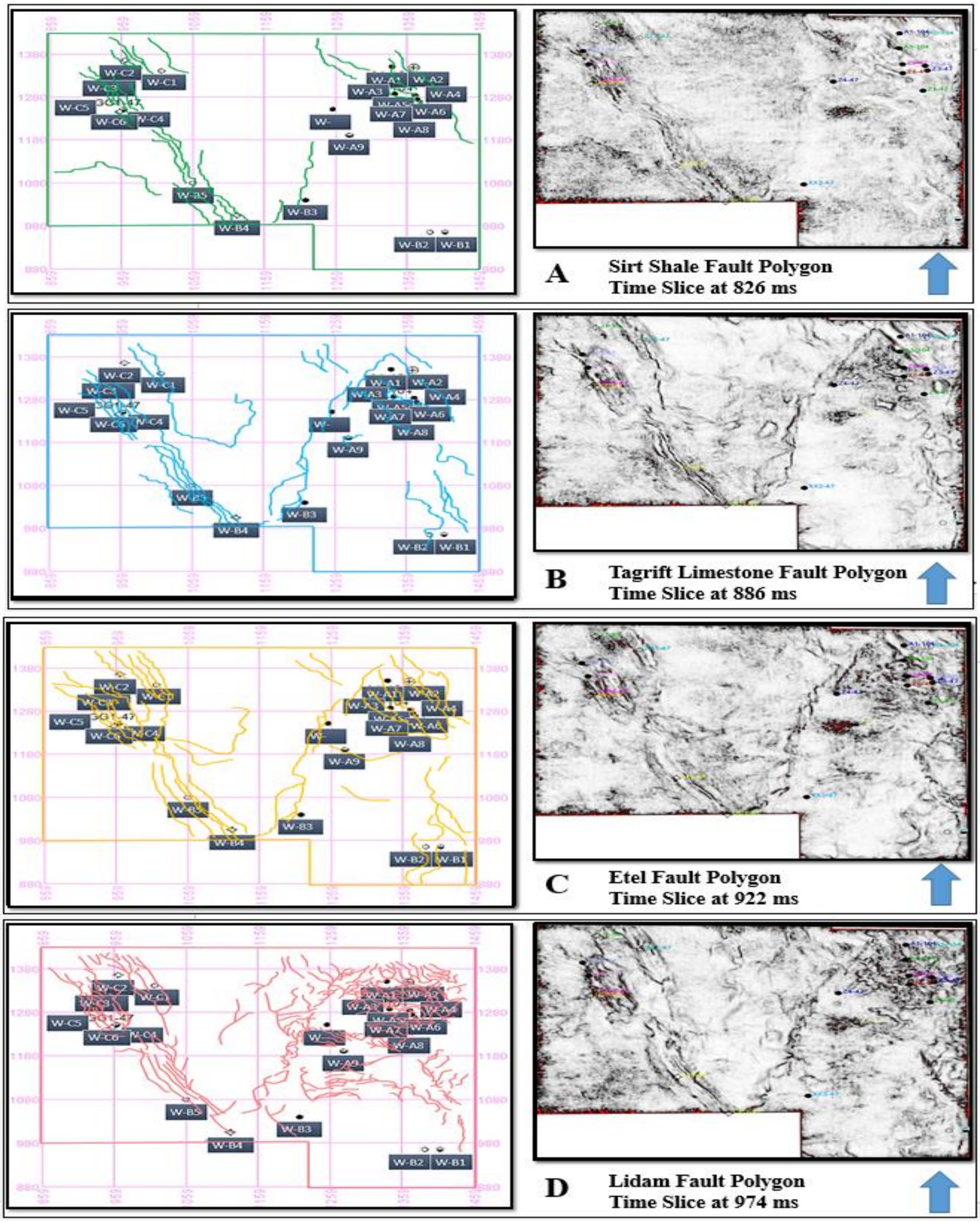

Fig. 11. Plan view of fault polygons, interpreted from the 3D seismic data for each formation showing the spatial and temporal changes in Upper Cretaceous geometry of faults that initiated and was re-activated during the Syn-rift phase (A) Sirt Shale, (B) Tagrift Limestone, (C) Etel and (D) Lidam Faults.

6. Interpretation of structure pattern

Prevailing fault orientation is NE-SW, dipping northwesterly and trending NW-SE direction, dipping southwesterly (Fig. 8). This is in response to the alternating compressional and extensional forces from the underlying strike-slip fault in the basement rock (Fig. 10C).

The marked similarities between the fault pattern in Bualwan, Dor Mansour fields and the Riedel shear pattern, suggests that their origin should be considered in terms of Riedel shear mechanisms. The major characteristic of Riedel shear is their en echelon pattern, it is obvious that minor faults are arranged like ridge ranges seem to consist of a linear group of minor individual ridges in en echelon pattern. The dominated NW-SE fault trend is, more or less, parallel to the fault zone trend. These faults are accompanied by NNW-SE trending fault related to the GFZ (Fig. 1).

Based on Naylor (1986), the orientation of the early Riedels are determined by initial stress state and that for maximum principle stress parallel and perpendicular to basement fault, the shear respectively low and high strike. This clearly suggests that the initial stress in Bulawan, Dor Mansour fields was oriented at a high angle to the trend of the fault zones, probably in an NE-SW alignment. Speculate en echelon pattern is developed in the NE-SW trend.

The formation of fault zone being with small overlapping fractures with tensional opening or shearing (Fig. 10B), the existence of R and P in place of tension gashes allows determining the sense of movement along the fault zone. The anticlockwise orientation (relative to the controlling slip vector) of the Riedel with respect to the trend of the major fault zones further indicates that the sense of displacement on the basement shear was sinistral, the research shows R-shear movement are antithetic with respect to the main fault. On the other hand, the maximum principal stress represented by vertical principal stress in the oblique extension.

7. Implication on hydrocarbon exploration

Bualwan, Dor Mansour fields have the appearance of a symmetric graben or half-graben structure, with similarities to an oblique extensional structure in rift basin. Hydrocarbon structural trap is complex and small size, which controlled the petroleum migration, accumulation and preservation. The main oil supply was from Sirt Shale Formation source rock, from Kotal-Graben by vertical migration along the fault (Hallet, 2002). Faulting was fairly active for a long time and occurrence of more new small faults, since the Early Cretaceous period caused oil escaping.

The transtensional movement of the NW-SE trend developed rollover anticline (Fig. 10B & C). The lateral movement of the master fault NE-SW trend (Figure 10B & C) released the compressional stress. The highly prospective area identified in the areas of flower structures but there are relatively small prospects.

8- Conclusion

Seismic attributes are very useful for the characterization of faults and fractures in 3D seismic data volumes. For example, Ant Tracker attribute is an effective tool suitable to enhanced fault interpretation in 3D seismic data set. As well as, Volumetric attribute such as chaos and structural smoothing attributes are very sensitive for fault detection.

Variance attributes are more suitable to show major faults that are not seen in the amplitude data. Especially after applied signal enhancing filters to remove residual noise to have an optimal result.

The structural patterns are complex and the major fractures are comprised of zones of minor faults arrange as en echelon. Riedel shear formed due to pure strike-slip are concave upwards “tulip shaped shear wedge”, and Plam tree structure Riedel convex upward; there has a component of a dip-slip, particularly where dip-slip displays reverse displacement.

In case of palm tree fault wedge, the study suggests in such a structural framework. The basement fault related to the strike-slip movement. The sinistral strike fault or oblique-dip slip is the manner of the deep-seated reactivation not simple dip-slip.

Two major fault zones would represent Riedel connected by P-shear and have developed in response to sinistral slip on major basement fault. Overall NW-SE trend consistent with the regional pattern NNW-SSE. Whereas the NE-SW structure modifies the pattern formed by the previous system to form the block structures. The highly prospective areas identified based on this study are the areas of positive flower structure but they are relatively small prospects.

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